PHENIX Experiment at RHIC: Quarkonium Measurement Capabilities

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Outline

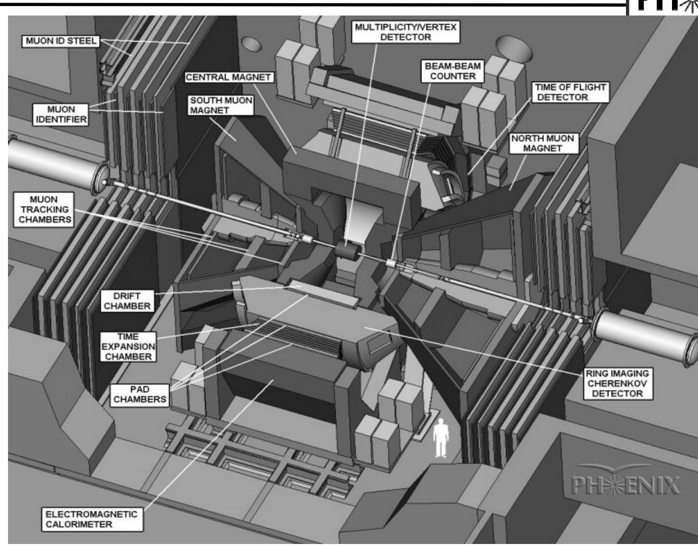
- **PHENIX Detector**
  - ★Centrality Measurement
  - ★Electron Measurement
  - ★Muon Measurement
- **Vector Meson Measurement**
- **Dilepton Spectra**
- **Expected Rates**
- **Conclusions**

Pioneering High Energy Nuclear Interaction eXperiment

Canada	**McGill University**	Russia	**Joint Institute for Nuclear Research**
China	**China Institute of Atomic Energy**	Russia	**Kurchatov Institute of Atomic Energy**
China	**Institute of High Energy Physics - Beijing**	Russia	**Petersburg Nuclear Physics Institute**
China	**Peking University**	Russia	**St. Petersburg State Technical University**
Germany	**University of Muenster**	Sweden	**Lund University**
India	**Banaras Hindu University**	USA-AL	**University of Alabama, Huntsville**
India	**Bhabha Atomic Research Centre**	USA-CA	**Lawrence Livermore National Laboratory**
Israel	**Weizmann Institute**	USA-CA	**University of California at Riverside**
Japan	**Center for Nuclear Study-U.Tokyo**	USA-FL	**Florida State University**
Japan	**Hiroshima University**	USA-GA	**Georgia State University**
Japan	**KEK, High Energy Accelerator Research Org.**	USA-IA	**Iowa State University / Ames Laboratory**
Japan	**Kyoto University**	USA-LA	**Louisiana State University**
Japan	**Nagasaki Institute of Applied Science**	USA-NM	**Los Alamos National Laboratory**
Japan	**RIKEN, Insitute of Physical and Chemical Research**	USA-NM	**New Mexico State University**
Japan	**Tokyo Institute of Technology**	USA-NM	**University of New Mexico**
Japan	**University of Tokyo (Physics Department)**	USA-NY	**Brookhaven National Laboratory**
Japan	**University of Tsukuba**	USA-NY	**Columbia University / Nevis Laboratory**
Japan	**Waseda University**	USA-NY	**State Univ. of New York at Stony Brook**
Korea	**Korea University**	USA-TN	**Oak Ridge National Laboratory**
Korea	**Yonsei University**	USA-TN	**University of Tennessee**
Russia	**Institute of High Energy Physics - Protvino**	USA-TN	**Vanderbilt University**

445 Collaborators in 10 Countries (44 Institutions)

The Detector

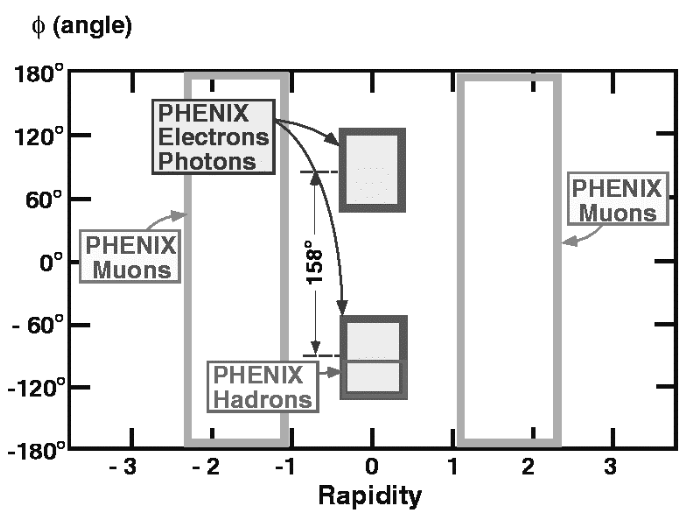


PHENIX Physics Philosophy

Seeing QGP will require correlation of many measurements:

- **Global event information**
  - ★ Multiplicity, E_T, fluctuations, $<p_T>$
- **Deconfinement**
  - ★ Differential suppression of ψ', J/ψ with respect to Υ
  - ★ J/ψ production relative to Drell-Yan, open charm production
- **Thermal History, Degrees of Freedom**
  - ★ Direct γ, direct $\gamma^* \rightarrow e^+e^-$, $\mu^+\mu^-$
- **Chiral symmetry restoration**
  - ★ Mass, width and branching ratio of $\phi \rightarrow e^+e^-$, K^+K^-
- **Space-time evolution**
  - ★ HBT correlation of $\pi\pi$, KK
- **Strangeness and Charm**
  - ★ $K^{\pm}$, K^0, ϕ, J/ψ, D production

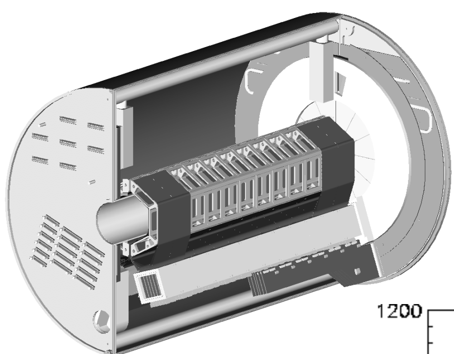
PHENIX acceptance



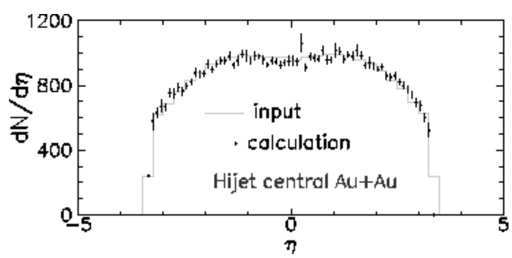
PHENIX Centrality Measurement

- **PHENIX will have several measurements of centrality and each of them will have different systematics:**
- **1) Charged particle multiplicity using MVD in the**
- **pseudorapidity range $-2.5 < \eta < 2.5$**
- **2) Transverse Energy measured in the Electromagnetic**
- **Calorimeter in the Central Arm which is $dE_T/d\eta$ at y=0**
- **3) Charged Particle Multiplicity as measured by the**
- **Central Arm tracking chambers and mean p_T .**
- **4) Zero degree Calorimeter to be installed at all collision**
- **points**

Multiplicity/Vertex Detector



- Wide coverage $|\eta|<2,5$
- 2 coaxial barrels, 200 μm wide silicon strip/pad
- 2 "end plates" of Si pads
- minimal radiation thickness



- 2mm 3D vertex accuracy
- Nch, $dNch/d\eta$
- sensitive to 10% fluctuations in Nch in 0.2 unit η rapidity bin

Central Arm Tracking Chambers

Drift Chambers (DC)

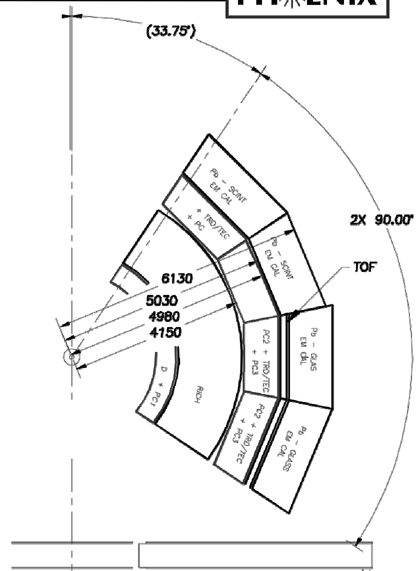
★ Low Mass multi-wire focussing drift chambers oriented to provide high resolution P_T measurements

Pixel Pad Chambers (PC)

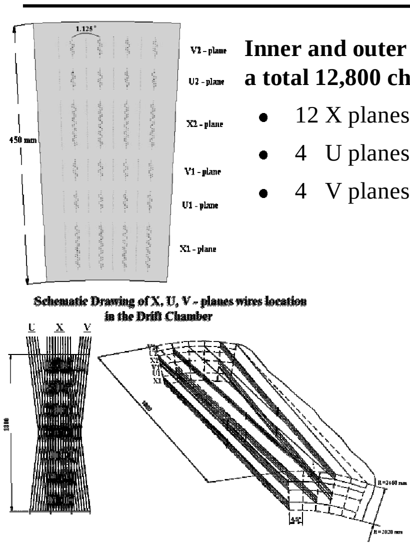
★ Non projective chambers providing three-dimensional position measurements to aid pattern recognition and measure P_Z/P_T and provide information to second level trigger

Time Expansion Chambers (TEC)

★ Provide tracking in front of the Electromagnetic Calorimeter and aid in global pattern recognition

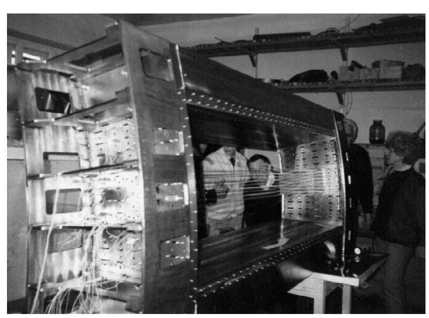


Drift Chamber

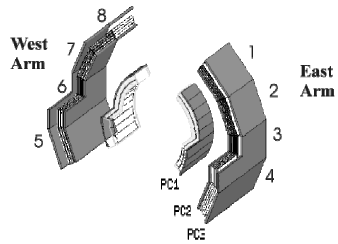


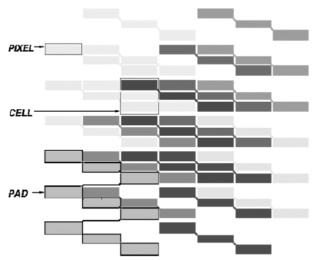
Inner and outer set of wires sharing the same gas volume for a total 12,800 channels. Each wire set has 3 orientations:

- 12 X planes (along z direction)
- 4 U planes (angle ≈ $+6^o$ with respect to z direction)
- 4 V planes (angle ≈ -6^o with respect to z direction)

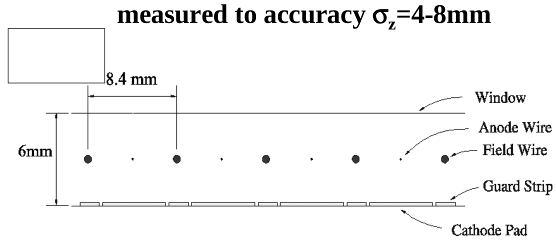


Pad Chambers

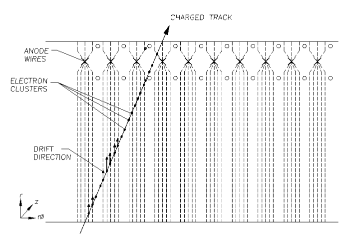


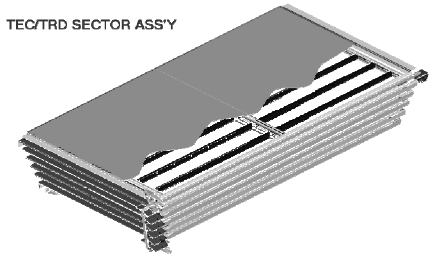


- **3 Pixel Pad Chambers divided in 8, 4 sectors covering $\eta = \pm 0.35$**
- **Staggered pixel pattern**
- **Low mass to minimize secondary particle production and multiple scattering (1-1.5%X_o)**
- **3 dimensional space points measured to accuracy σ_z=4-8mm**



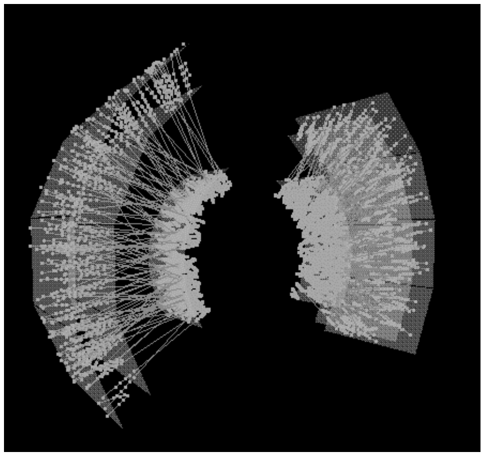
Time Expansion Chambers





- **4 sectors/arm with 6 planes/sector**
- **single point track resolution of 250μm in the r-ϕ direction**
- **Day 1 4 planes will be instrumented for a total of 29,000 channels**
- **Contribute to p_T measurement above 2GeV/c**
- **Determine particle species using dE/dx information**

Tracking Detector Performance



Drift Chamber

- position resolution of 150 µm in r-φ and 2 mm in z
- 2 track separation is 1.5 mm

Pixel Pad Chamber

- 3-d space point with accuracy of 3-8mm (PC1-3)

Time Expansion Chamber

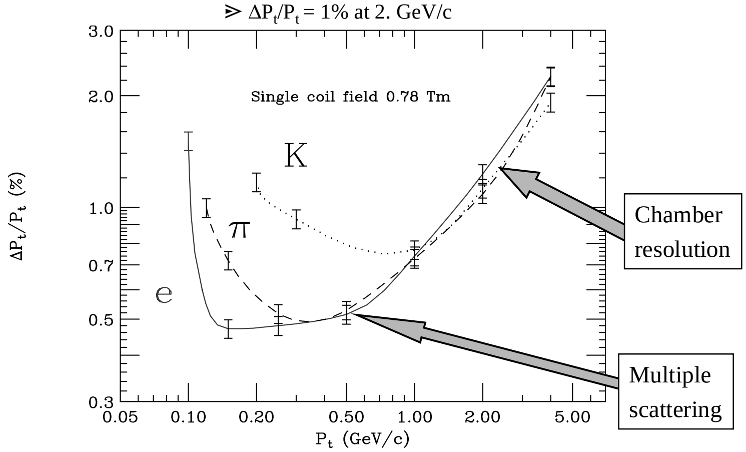
- single point track resolution of 200-250µm in the r-φ direction
- 2track separation of 5mm for tracks normal to the detector

Using DC, PC and TEC, the trajectory can be reconstructed.for all charged particles within the Central Arm acceptance

Electron Momentum Resolution

Combining the information on trajectory and magnetic field, particle momenta are determined

- $\Delta P_t/P_t$ = 1% at 2. GeV/c



Central Arm Electron Identification

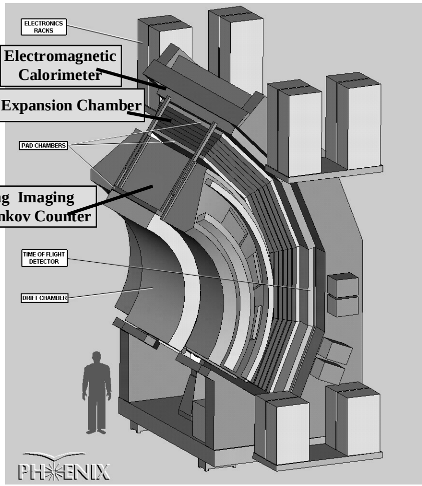
- **Electromagnetic Calorimeters**

  High Resolution, high granularity detector provide electron identification $\pi/e < 10^{-2}$ for momentum > 1.5 GeV/c
- **Time Expansion Chamber**

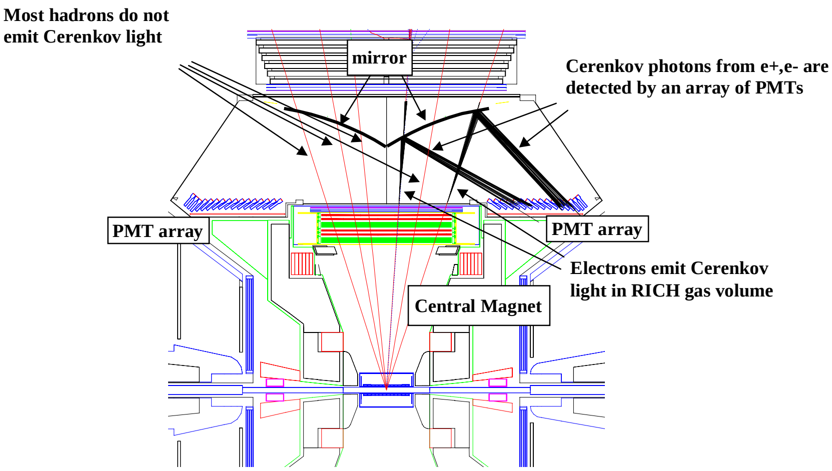
  dE/dx measurement allowing π/e separation at 1 GeV/c of $<10^{-2}$ with P10 gas and 4 planes instrumented and 2×10^{-3} with Xe gas and 6 planes instrumented .
- **Ring Imaging Cherenkov Detector**

  π/e separation < 10^{-4} for a single charged pion with momentum <4GeV/c.

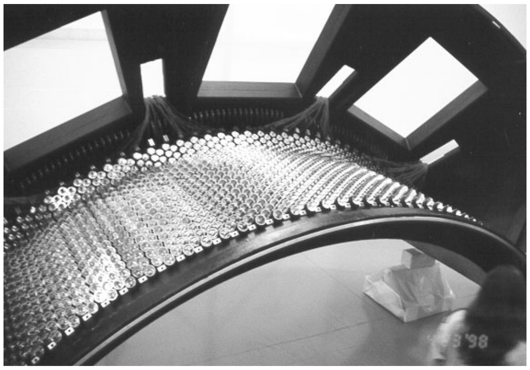
  Electron efficiency > 90% up to 4GeV/c.



Ring Image Cherenkov Detector



RICH



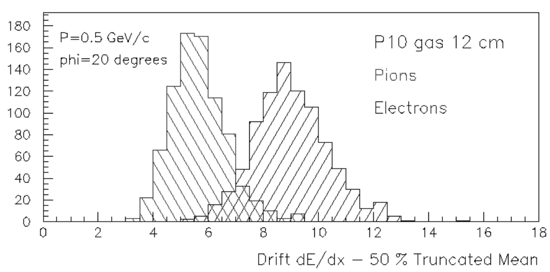
Construction Status:

Two gas vessels has been constructed at FSU, and they are now at BNL

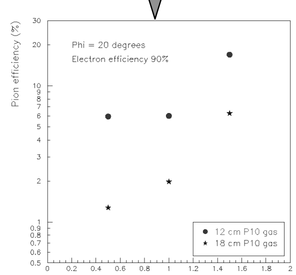
All of 2560 PMTs has been installed in the first vessel

- ★ Electron identification efficiency ~100% for a single electron with momentum less than ~ 4 GeV/c
- ★ Pion rejection factor: > 10^3 for a single charged pion with momentum less than ~ 4 GeV/c
- ★ Ring angular resolution: ~ 1 degree in both θ and ϕ

TEC e/π



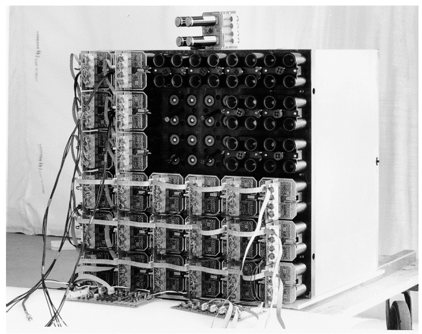
Testbeam results
AGS, June 96

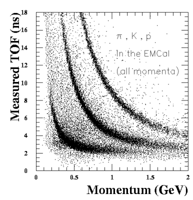


Using dE/dx information:

- **e/π=5% at 500 MeV/c with P10 gas (day1)**
- **e/π<2% at 500 MeV/c with Xe gas (upgrade)**
- **upgrade to insert foil radiator between all layers and instrument 6 planes will improve PID at high momentum**

Electromagnetic Calorimeter





Timing Resolution:

★ PbSc ~ 250ps

★ PbGl ~ 400ps

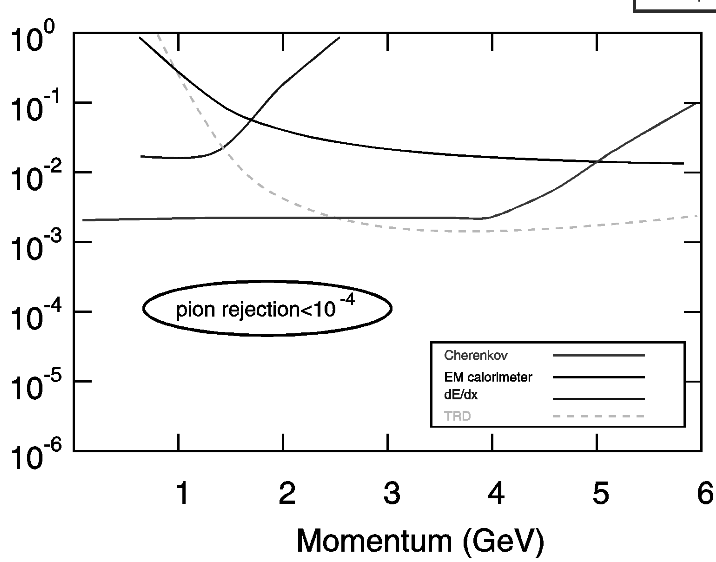
- **6 Sectors PbSc, 2 Sectors PbGl for a total of 28,224 channels**
- **High Granularity**
  - ★ cell size 5x5x37,4x4x40 cm^3
  - ★ 2% primary particle occupancy
- **Sampling fraction 20%,100%**
- **Energy Resolution**

$$\frac{\sigma_E}{E} = \frac{8\%}{\sqrt{E(GeV)}} \oplus 1.5 \quad , \quad \frac{5.8\%}{\sqrt{E(GeV)}} \oplus 1.$$

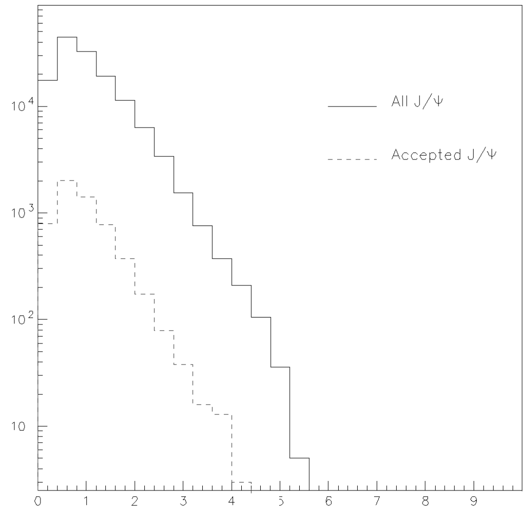
- **Spatial Resolution**

$$\sigma_x(mm) = \frac{10.}{\sqrt{E(GeV)}} \quad , \quad \frac{5.}{\sqrt{E(GeV)}} \oplus 1.$$

PHENIX π Rejection

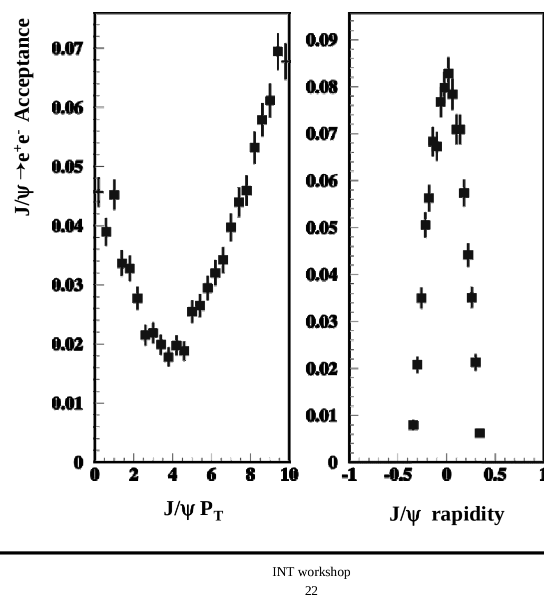


J/ψ →e⁺e⁻ Transverse Momentum



5/13/98 INT workshop 21 *Marzia Rosati* *Iowa State University*

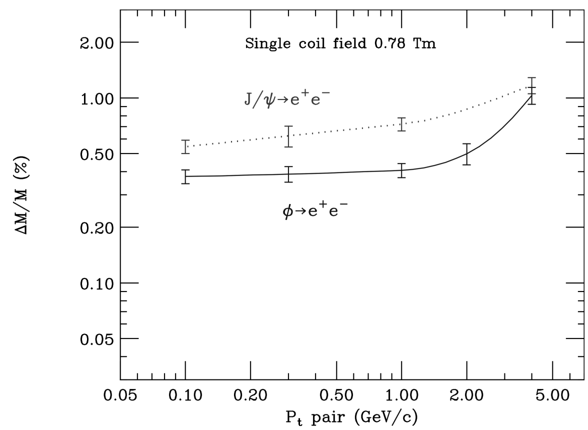
J/ψ →e⁺e⁻ Acceptance vs P_T and rapidity



5/13/98 INT workshop 22 *Marzia Rosati* *Iowa State University*

J/ψ → e⁺e⁻ Invariant Mass Resolution

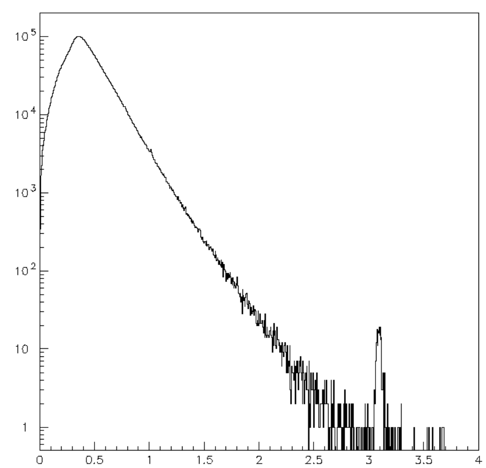
PHENIX



J/ψ Mass Resolution is ≅ 20 Mev/c² and shows a weak dependence on the p_T of the electron pair

Dielectron invariant mass

PHENIX



e^+e^- Invariant Mass (GeV/c²)

18 M Au+Au Central collisions

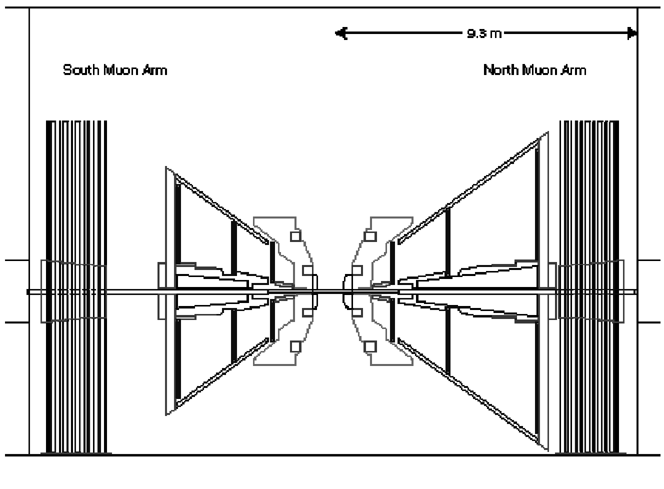
1/2 week with full Luminosity of RHIC

Events are fully simulated using Geant

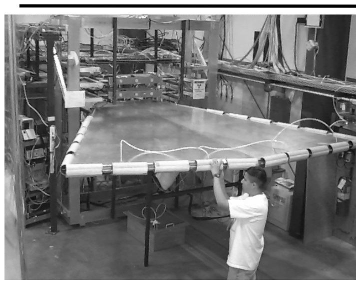
Main source of background are Dalitz decays and photon conversions.

An anomalous suppression factor of 0.5 was assumed.

Muon Arms



Muon Tracking and Muon ID Detectors



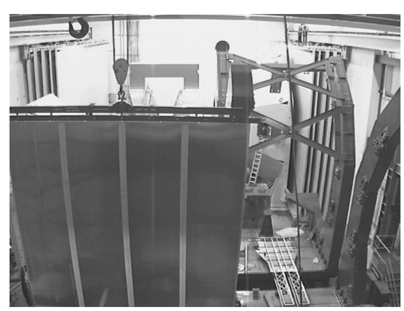
Muon Tracking

3 stations of 3 cathode strip chambers (CSC)

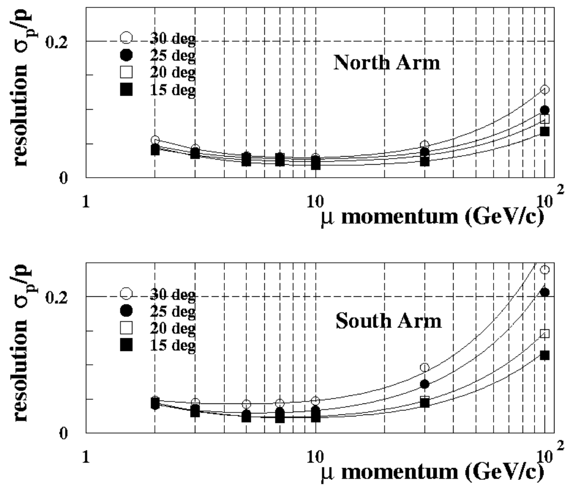
- one fine cathode plane, $\sigma \sim 100\ \mu m$
- one coarse cathode plane at a stereo angle of 22.5 degrees
- anode plane which is perpendicular to the fine cathode plane

Muon ID

- 6 walls of steel absorber interleaved with layers of Iarocci proportional tubes
- Low energy muon threshold of ~2.2 GeV
- $\pi/\mu \sim 10^{-4}$
- **First panel installed a week ago!**

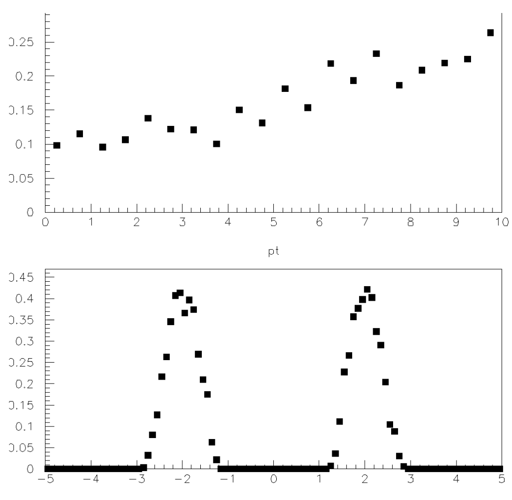


Muon Arm Momentum Resolution



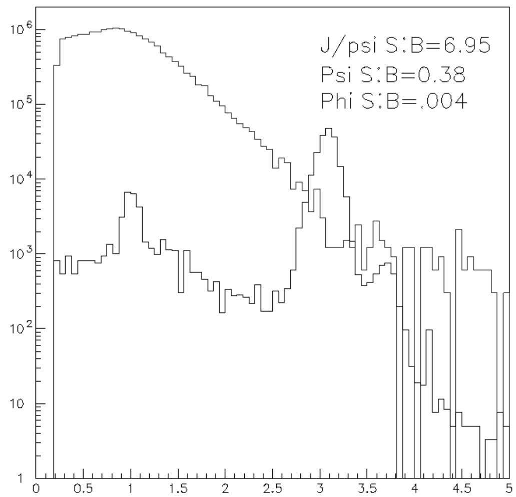
5/13/98 INT workshop 27 *Marzia Rosati* *Iowa State University*

$J/\psi \rightarrow \mu^+\mu^-$ Acceptance vs P_T and rapidity



5/13/98 INT workshop 28 *Marzia Rosati* *Iowa State University*

J/ψ —> $\mu^+\mu^-$ Invariant Mass



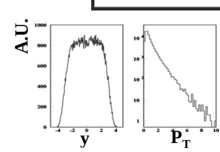
Drell Yan
Charm Production
Vector Mesons

background

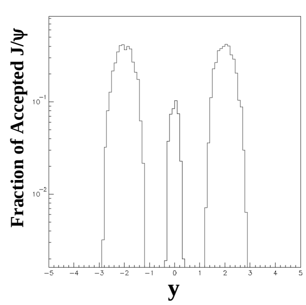
1 RHIC year at design luminosity Minimum Bias NO ANOMALOUS SUPPRESSION is included

Detector Acceptance for J/ψ → dileptons

Using the p-N cross section predictions as calculated at NLO for the transverse momentum and rapidity distribution



Acceptance is the percentage of J/ψ which have both electrons going through the detector



For J/ψ →$\mu^+\mu^-$

$$\frac{N_{J/\psi}(accepted)}{N_{J/\psi}(total)} = 8.6\%$$

For J/ψ →e^+e^-

$$\frac{N_{J/\psi}(accepted)}{N_{J/\psi}(total)} = 0.75\%$$

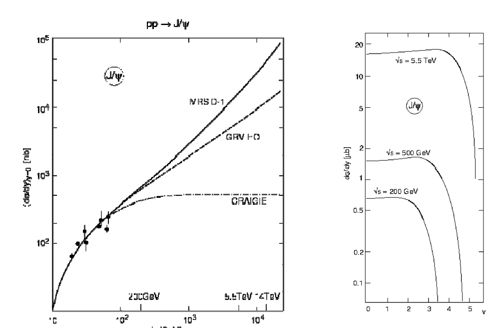
J/ψ Invariant Mass Resolution and Acceptances

PHENIX

Particle	Mass Resolution (MeV/c^2)	Acceptance (%)
$J/\psi \to \mu\mu$	105	8.6
$\psi' \to \mu\mu$	105	8.6
$\Upsilon \to \mu\mu$	180	8.3
$\psi \to ee$	20	0.75
$\psi' \to ee$	20	0.75

J/ψ Cross Section in pN Collisions

PHENIX



R. Gavai, D.Kharzeev, H. Satz, G.A. Schuler, K. Sridhar, R. Vogt
Int. J. Mod. Phys. A10 (1995) 3043

Next to leading calculations predict the J/ψ cross section as shown in this figure using an overall normalization factor:

$$\left(\frac{d\sigma_{pN\to J/\psi}}{dy}\right)_{y=0} = 2.5\times10^{-2}\left(\frac{d\sigma_{c\bar{c}NLO}}{dy}\right)_{y=0}$$

The agreement with existing data is quite good (CDF at igh p_T) and the prediction at RHIC energies is:

$$\left(\frac{d\sigma_{pN\to J/\psi}}{dy}\right)_{y=0} = (5.9-6.3)\times10^{-1}\,\mu b$$

Knowing $BR(\psi \to e^+e^-, \mu^+\mu^-) = 6.0\%$

$$\left(\frac{d\sigma_{pN\to J/\psi}}{dy}\right)_{y=0} BR(J\to ee,\mu\mu) = (35-38)nb \qquad \sigma_{pN\to J/\psi}\ BR(J\to ee,\mu\mu) = (185-200)nb$$

A-dependence of J/ψ Cross Section

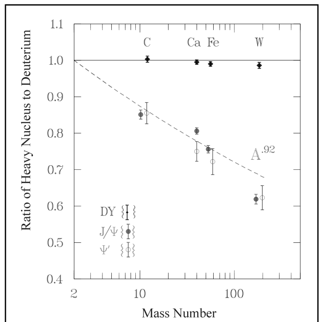
J/ψ Cross Section in proton-Nucleus collision shows a nuclear dependence which can be parameterized as:

$$\sigma_{AA\to J/\psi} = A^{2\alpha}\sigma_{pN\to J/\psi}$$

with α =0.92 (shown in figure)

Assuming there is **no new physics** in AA collision we can estimate J/ψ Cross Section in Au-Au collisions at RHIC energies is estimated as:

$$\sigma_{AA\to J/\psi} BR(J/\psi \to ee,\mu\mu) = 3.3mb$$



E772 Collaboration, D.M. Alde et al.
Phys. Rev Lett 66 (1991) 63

Estimate of J/ψ Integrated Yield in one Year of RHIC

Assuming there is **no anomalous J/ψ suppression** we can calculate an upper limit to the J/ ψ Integrated Yield.

We estimate one year of running for 8 months corresponds to 10^7 seconds, to account for detector and accelerator down time(50%). Using the RHIC design luminosity L= 2x 10^{26} cm^{-2} s^{-1}.Then the total number of J/ψ produced is:

$$N_{J/\psi}(total) = 6.3\times 10^6\, events$$

Within the PHENIX acceptance we have:

Particle	Dimuon Decay	Dielectron Decay
J/ψ	530k	53K
ψ'	9k	0.9k
Y	0.8k	

Conclusions

- Within one year of RHIC running at full luminosity we will have data sample of size comparable to NA50 for J/ψ
- PHENIX has capabilities of measuring several charmonium states
- RHIC will allow pp, pA, AA collisions therefore we will be able to make a systematic study of charmonium and bottonomium production providing STRINGENT CONSTRAINTS on production/suppression theoretical models.

We need input from the theorists!!!!

Dilepton Mass Spectrum: Theory Prediction